APPENDIX F

# Water Temperature Monitoring

# Water Temperature Monitoring

PREPARED FOR: Upper Yuba River Studies Program

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## Introduction

Stream temperature is an important consideration when evaluating the feasibility of introducing Chinook salmon and steelhead to the upper Yuba River. Accordingly, members of the habitat study team monitored water temperatures at various locations in the upper Yuba River watershed. Monitoring began in 2003 to provide the baseline data on current water temperatures in the Upper Yuba River Studies Program (UYRSP) study area. The baseline data also provides calibration and validation data sets for the water temperature model being developed for the watershed.

To examine whether warming of water was occurring in the canal system, additional monitoring locations in the canal system that routes water from Milton Reservoir on the Middle Yuba River through Bowman Lake and into Lake Spaulding on the South Yuba River were established in 2004. Two additional monitoring locations were also established above Lake Spaulding in Fordyce Creek and the South Yuba River to examine the relationship between Lake Spaulding inflow temperatures and outflow temperatures. Also in 2004, water temperature profiles were conducted monthly from July through October in four upper reservoirs to help determine the extent of the cold water pool that may form in the depths of the reservoirs.

This technical memorandum describes the methods used to monitor stream temperatures in the upper Yuba River watershed and obtain water temperature profiles in the reservoirs. It also presents results of the water temperature monitoring, including the longitudinal distribution of stream temperatures in the mainstem rivers, stream temperatures in several tributaries to the Middle and South Yuba rivers, water temperatures in the canal system and streams tributary to Lake Spaulding, and the vertical profiles of water temperature in the upper basin reservoirs. Stream temperatures are presented as daily averages, maximums, and minimums.

## Monitoring Equipment

### Stream Temperature Monitoring

HOBO® Water Temp Pro data loggers were obtained from Onset Computer Corporation (Onset) for use in monitoring stream temperatures. These data loggers are accurate to ±0.2 degrees Celsius [°C] at 0°C to 50°C (±0.36 degrees Fahrenheit [°F] at 32°F to 120°F), with a response time of 5 minutes in water, 12 minutes in air (typical to 90 percent).

BoxCar Pro®, a program with features for graphing, data analysis, data export and simultaneous management of multiple loggers was chosen for the water temperature monitoring program. The data loggers were downloaded via infrared communication to a Palm™ i705 handheld device. This device also was used to relaunch the data loggers in the field. HandCar Ex® software, provided by Onset was used to allow communication between the data loggers and the Palm™ handhelds.

### Reservoir Profiling

California Department of Water Resources (DWR) staff in the Sacramento water quality laboratory provided a Model 3000 T-L-C Meter manufactured by Yellow Springs Instruments, Inc. The Model 3000 T-L-C Meter is a self-contained field instrument and probe system that measures temperature, conductivity, and temperature-compensated conductivity for water quality applications. Temperature is measured by means of a precision thermistor assembly built into the probe housing, and is expressed in degrees Celsius. The 150-foot probe cable is marked at one-foot intervals for ease in determining depth. Range of the temperature thermistor is -5°C to 50°C (23°F to 122°F) with accuracy to ±0.3°C and resolution to 0.1°C. The probe is accurate for temperature changes in 40 to 60 seconds. Only the temperature capabilities were used during the reservoir profiling.

## Monitoring Locations

### Streams and Tributaries in the Study Area

**Site Selection.** The goal of the monitoring program was to collect stream temperature data at more or less regular intervals along the long profile of the mainstem rivers from the upstream reservoir release points downstream to the mouth. Locations near existing flow measurement stations and where major tributaries enter the mainstem rivers were of particular interest. Due to the ruggedness of the canyons, particularly in the upstream reaches, and the limited number of access points along the rivers, it was not feasible to establish an evenly spaced set of locations or to access every tributary. The habitat team selected monitoring locations that provided the best combination of spacing, tributary coverage, and access available given the limitations on access.

**Locations and Periods of Record.** From May through July 2003, data loggers were installed at several locations in the mainstem Middle and South Yuba rivers. On the North Yuba River, data loggers were installed below New Bullards Bar Dam, downstream of the confluence with the Middle Yuba, and just upstream of Colgate Powerhouse. Tributaries to the Middle Yuba River where data loggers were installed included Wolf Creek, Kanaka Creek, and Oregon Creek. On the South Yuba River, data loggers were installed in Canyon Creek, Poorman Creek, Spring Creek, Rock Creek and Rush Creek. Where suitable locations were available at these tributary locations, data loggers were installed in the tributaries and in the mainstem immediately upstream and downstream of the tributary inflow to examine the effect of tributary inflows on water temperatures in the mainstem river. Two additional locations were added along the South Yuba River in 2004. Figure 1 shows the locations of all data loggers installed as part of the UYRSP.

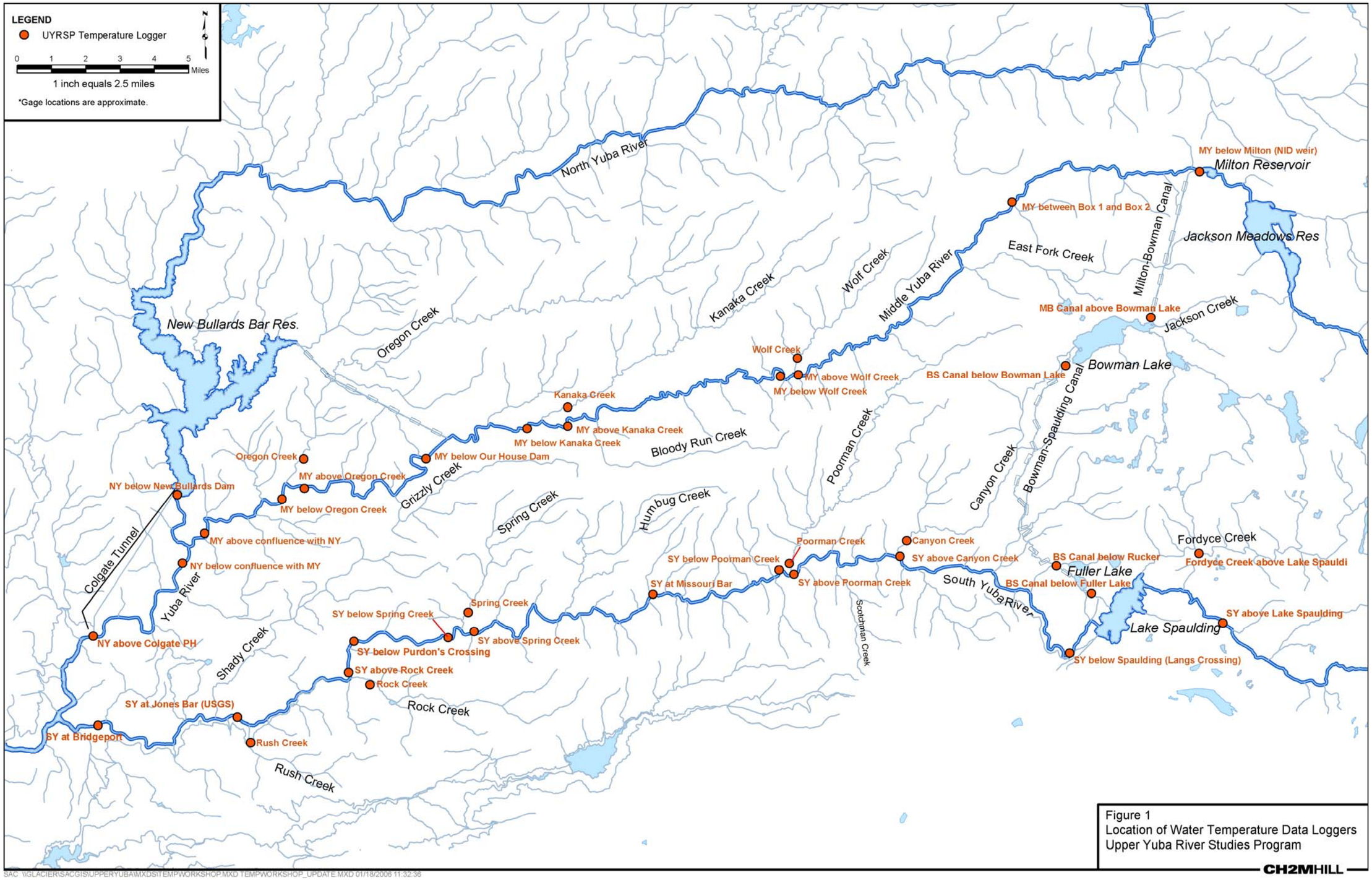


Figure 1
Location of Water Temperature Data Loggers
Upper Yuba River Studies Program

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The data loggers were initially set up in the office so that all recording parameters were preset and only required a "launch" in the field using the Palm™ handhelds. All of the data loggers installed in 2003 were preset to a recording interval of 15 minutes to maximize the amount of information collected on daily variations in temperature. At this recording interval, the memory capacity of the loggers would be exceeded in approximately 7 months.

The first downloads were initiated in September of 2003. At that time, some of the data loggers were unable to be located due to removal by others (vandalism) or loss due to high flows during the runoff period; missing loggers were replaced at that time. A second download was attempted in April 2004. High water in 2004 prevented the download of several loggers and many were not downloaded until later in the year. As in 2003, some of the loggers were vandalized or otherwise lost before they could be downloaded. Also, several of the loggers had exceeded their memory capacity before downloading, creating gaps in the time series recorded. During the late-summer download, most of the loggers were reset to a sampling interval of 1-hour to prolong the period that they would record before exceeding their memory capacity. Data loggers were next downloaded in September and November of 2005. Table 1 indicates the periods of record for each monitoring location.

TABLE 1
Water Temperature Monitoring Locations and Periods of Record in the Upper Yuba River Watershed

| Monitoring Location | Period of Record | Comments |
|---|---|---|
| **Middle Yuba** | | |
| Below Milton Dam | 6/11/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 11/14/2005 | |
| Between Box Canyons 1 and 2 | 6/19/2003 to 12/31/2003<br>1/1/2004 to 4/28/2004<br>7/9/2004 to 12/31/2004<br>1/1/2005 to 9/18/2005 | Memory full 4/28/2004 |
| Above Wolf Creek | 6/19/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 9/21/2005 | |
| Below Wolf Creek | 6/19/2003 to 12/31/2003<br>1/1/2004 to 4/28/2004 | Memory full 4/28/2004 |
| Above Kanaka Creek | 6/23/2003 to 12/31/2003<br>1/1/2004 to 4/26/2004 | Memory full 4/26/2004 |
| Below Kanaka Creek | 6/4/2003 to 12/31/2003<br>1/1/2004 to 9/16/2004<br>1/1/2005 to 5/19/2005 | Logger recovered broken |
| Below Our House Dam | 5/27/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 11/15/2005 | |
| Above Oregon Creek | 5/27/2003 to 12/31/2003<br>1/1/2004 to 8/25/2004 | |
| Below Oregon Creek | 5/27/2003 to 12/31/2003<br>1/1/2004 to 8/25/2004 | Missing in November 2005 |
| Above Confluence with North Yuba | 6/18/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 11/14/2005 | |

TABLE 1
Water Temperature Monitoring Locations and Periods of Record in the Upper Yuba River Watershed

| Monitoring Location | Period of Record | Comments |
|---|---|---|
| Wolf Creek (tributary) | 6/19/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 9/21/2005 | |
| Kanaka Creek (tributary) | 7/23/2003 to 9/15/2003<br>4/28/2004 to 9/16/2004 | Found broken in April 2004, replaced,<br>Missing in September 2004 |
| Oregon Creek (tributary) | 5/27/2003 to 12/31/2003<br>1/1/2004 to 8/25/2004 | <br>Missing in November 2005 |
| **North Yuba** | | |
| Below New Bullards Bar Dam | 6/3/2003 to 12/31/2003<br>1/1/2004 to 8/25/2004 | <br>Missing in November 2005 |
| Below Confluence with Middle Yuba | 6/18/2003 to 12/31/2003<br>1/1/2004 to 8/25/2004 | <br>Missing in November 2005 |
| Above Colgate Powerhouse | 6/4/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 11/15/2005 | |
| **South Yuba** | | |
| Below Langs Crossing | 6/11/2003 to 12/31/2003<br>1/1/2004 to 9/13/2004 | <br>Missing in November 2005 |
| Above Canyon Creek | 7/24/2003 to 12/31/2003<br>1/1/2004 to 4/28/2004<br>9/15/2004 to 12/31/2004<br>1/1/2005 to 9/22/2005 | <br>Missing in September 2004, replaced |
| Above Poorman Creek | 6/16/2003 to 9/6/2003<br>4/29/2004 to 7/4/2004 | Missing in April 2004, replaced<br>Vandalized July 2004 |
| Below Poorman Creek | 6/16/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 9/22/2005 | |
| At Missouri Bar | 6/17/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 8/3/2005 | <br><br>Recovered out of water, November 2005 |
| Above Spring Creek | 6/16/2003 to 9/18/2003<br>4/29/2004 to 8/23/2004 | Missing in April 2004, replaced |
| Below Spring Creek | 6/17/2003 to 12/31/2003<br>1/1/2004 to 4/28/2004 | <br>Missing in September 2004, replaced<br>Missing in November 2005, replaced |
| Below Purdon's Crossing | | All loggers lost before downloading |
| Above Rock Creek | 4/29/2004 to 12/31/2004<br>1/1/2005 to 11/18/2005 | |
| Above Rush Creek | 4/27/2004 to 8/25/2004 | Removed from USGS gage, August 2004 |
| Below Rush Creek | 9/15/2003 to 12/31/2003<br>1/1/2004 to 4/27/2004<br>9/25/2004 to 12/31/2004<br>1/1/2005 to 11/14/2005 | Memory full 4/27/2004 |
| At Bridgeport | 6/3/2003 to 6/17/2003<br>4/28/2004 to 9/14/2004 | Missing in September 2003, replaced<br>Missing in April 2004, replaced<br>Missing in November 2005 |

TABLE 1
Water Temperature Monitoring Locations and Periods of Record in the Upper Yuba River Watershed

| Monitoring Location | Period of Record | Comments |
|---|---|---|
| Canyon Creek (tributary) | 6/16/2003 to 12/31/2003<br>1/1/2004 to 4/29/2004 | Missing in September 2004 |
| Poorman Creek (tributary) | 5/27/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 9/22/2005 | |
| Spring Creek (tributary) | 5/28/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 11/17/2005 | |
| Rock Creek (tributary) | 6/15/2003 to 12/31/2003<br>1/1/2004 to 12/31/2004<br>1/1/2005 to 11/18/2005 | |
| Rush Creek (tributary) | 5/27/2003 to 12/31/2003<br>1/1/2004 to 12/08/2004 | Memory full December 2004 |

## Reservoir Profiles

To help determine the extent of the cold water pool that may form in the depths of the upstream reservoirs, water temperature profiles were conducted monthly from July through October in Jackson Meadows, Bowman Lake, Fordyce Lake, and Lake Spaulding. Profiles were conducted from a small aluminum boat equipped with an outboard motor. Profiles were conducted in what the team determined to be the deepest areas of the lakes. Without lake contour data, the deepest areas could only be approximated from the visible reservoir slopes, location of the outlets, and by probing with the temperature probe to find the deepest spot in a general location. Wind made holding a steady position difficult, but by using the motor and a "back trolling" technique it was possible to maintain a near-stationary position. General positions where the profiles were conducted were recorded using a handheld global positioning system (GPS) unit. Temperature readings were only taken when the cable was vertical in the water column. Water temperatures were recorded at the surface, 1 foot in depth, 2 feet in depth, and every 2 feet to the lake bottom or the extent of the probe cable (150 feet). Table 2 indicates the dates that profiles were conducted in each reservoir.

TABLE 2
Reservoir Water Temperature Profile Locations and Dates in the Upper Yuba River Watershed

| Profile Location | Dates | Comments |
|---|---|---|
| Jackson Meadows | 7/12/2004<br>8/19/2004<br>9/13/2004<br>10/14/2004 | |
| Bowman Lake | 7/12/2004<br>8/19/2004<br>9/13/2004<br>10/14/2004 | |
| Lake Spaulding | 7/12/2004<br>8/19/2004<br>9/13/2004<br>10/15/2004 | Depths exceeded 150-foot cable length on all dates |

TABLE 2
Reservoir Water Temperature Profile Locations and Dates in the Upper Yuba River Watershed

| Profile Location | Dates | Comments |
|---|---|---|
| Fordyce Lake | 7/13/2004<br>8/20/2004<br>9/14/2004<br>10/15/2004 | |

### Canals and Streams Outside the Study Area

Above the study area, water from the Middle Yuba River drainage is routed through a series of canals and tunnels connecting the upper reservoirs and lakes, eventually reaching the South Yuba River drainage. Data collected in 2003 suggested that the South Yuba River below Lake Spaulding was considerably warmer than the Middle Yuba River below Milton Reservoir. To examine whether warming of water was occurring in the canal system, additional monitoring locations in the canal system that routes water from Milton Reservoir on the Middle Yuba River through Bowman Lake and into Lake Spaulding on the South Yuba River were established in 2004. Two additional monitoring locations were also established above Lake Spaulding in Fordyce Creek and the South Yuba River to examine the relationship between inflow temperatures and outflow temperatures. Table 3 indicates the periods of record for each location in the canal system and upstream of Lake Spaulding.

TABLE 3
Canal and Stream Water Temperature Monitoring Locations and Periods of Record in the Upper Yuba River Watershed

| Monitoring Location | Period of Record | Comments |
|---|---|---|
| Milton-Bowman Canal above Bowman Lake | 7/9/2004 to 12/31/2004<br>1/1/2005 to 8/28/2005 | Logger recovered broken |
| Bowman-Spaulding Canal below Bowman Lake | 7/9/2004 to 12/31/2004<br>1/1/2005 to 9/19/2005 | |
| Bowman-Spaulding Canal below Rucker Creek | 7/9/2004 to 12/31/2004<br>1/1/2005 to 9/19/2005 | |
| Bowman-Spaulding Canal below Fuller Lake | 7/9/2004 to 12/31/2004<br>1/1/2005 to 9/19/2005 | |
| South Yuba above Lake Spaulding | 7/10/2004 to 9/13/2004 | Missing in November 2005 |
| Fordyce Creek above Lake Spaulding | 7/10/2004 to 12/31/2004<br>1/1/2005 to 11/14/2005 | |

## Installation of Data Loggers

At each location, care was taken to select a site within a section of flowing water with sufficient depth to avoid dewatering if flows were reduced. The risk of dewatering was minimized by installing the loggers at near low base-flow conditions. At most sites it was possible to find an area in the thalweg of the stream with cobble/boulder substrates. In these areas it was possible to drive a long nail (tent stake) between the cobbles to use as an anchor for cabling the logger in place. The cable and logger were then placed along the stream

bottom and cobbles placed on the cable to both anchor it further and conceal the cable and logger to avoid detection and vandalism. At some sites, it was possible to attach the cable to submerged roots of emergent vegetation or natural holes formed where two large boulders rested together. The cables and loggers were then concealed with cobbles or within the bubble curtain created by the boulders. Within the canal system, loggers were typically cabled to hard points such as metal supports, railings, or other in-canal equipment or structures. During periods of higher flow when loggers could not safely be installed in the mainstem, rock gabions constructed of chicken-wire mesh enclosing cobbles and the data logger were placed in pools and recovered later once flows had receded.

At each of the monitoring sites, a description of the logger placement within the channel was recorded and photos of each site were taken to aid in locating the loggers for downloading in the future. Where satellite coverage allowed, a handheld GPS receiver was used to obtain the latitude/longitude at each site to aid in relocating the loggers and to provide coordinates for mapping of monitoring sites.

## Results

### Stream Temperatures

**Daily Variability.** Stream temperatures exhibited a high level of variation during each day at most sites, particularly during the summer. The upstream sites exhibited less hourly variation than downstream sites (Figures 2A, 2B, 3A, and 3B).

**Temporal and Spatial Variability.** To summarize the periodic (15-minute to 1-hour interval) water temperature measurements, the daily average was calculated for each day of the period of record at each monitoring location. The daily average is the mean of all periodic temperature readings on a given day.

Figures 4A, 4B, and 4C presents the daily average water temperatures recorded at selected mainstem monitoring locations along the Middle Yuba River in 2003, 2004 and 2005. Figures 5A, 5B, and 5C present the daily average water temperatures recorded at selected mainstem monitoring locations along the South Yuba River in 2003, 2004 and 2005.

Several general trends in stream temperature are apparent from the monitoring data collected to date:

- Stream temperatures at the most upstream monitoring locations are relatively constant throughout the year.
- Stream temperatures increase in a downstream direction from the most upstream monitoring locations.
- Stream temperatures increase most rapidly in the reaches immediately downstream of the uppermost monitoring sites, reaching more or less “equilibrium” conditions at downstream locations.
- The highest stream temperatures are recorded in late July and early August.

- Tributary inflows have little effect on mainstem river temperatures; where an effect is noted (Poorman Creek and Oregon Creek), it is spatially limited to a short distance downstream of the inflow point.

Differences between the South Yuba and Middle Yuba rivers include:

- Stream temperatures at the uppermost monitoring location on the South Yuba River (below Langs Crossing) are generally around 5.5°C (10°F) warmer than at the uppermost location on the Middle Yuba River (below Milton Dam).
- The difference in upstream temperatures between the Middle Yuba and South Yuba rivers diminishes in a downstream direction resulting in similar stream temperatures in the lower reaches of both rivers.

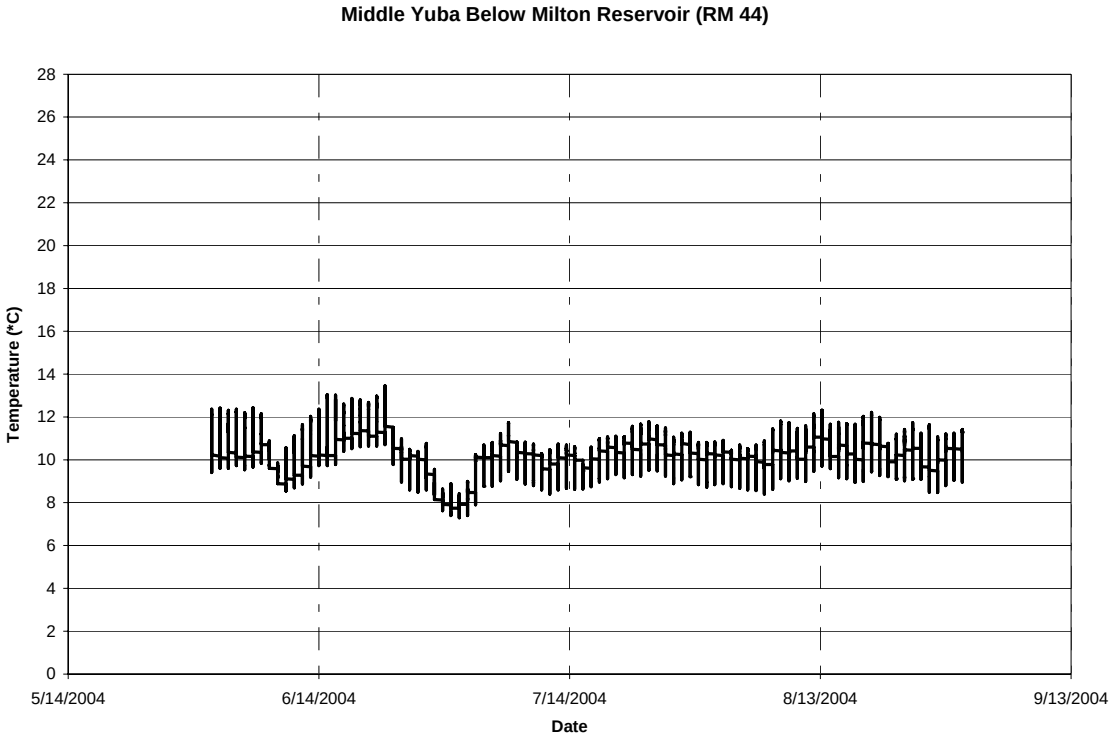


FIGURE 2A
Summer Water Temperatures in the Middle Yuba River below Milton Reservoir (15-minute interval)

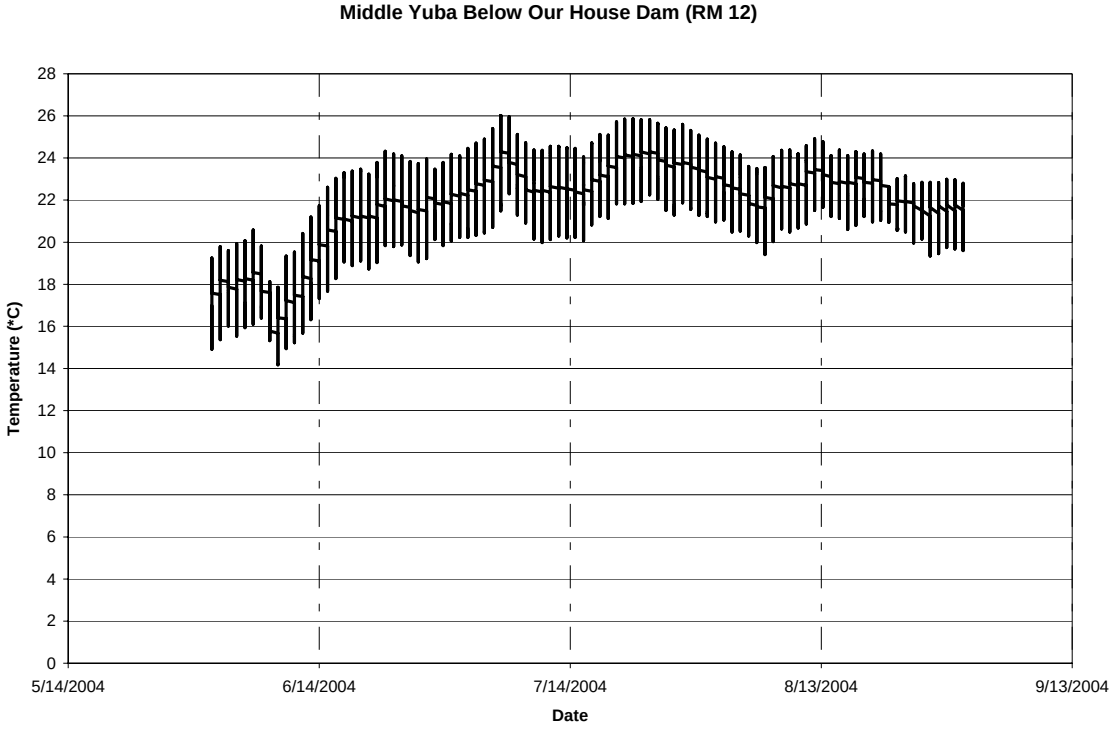


FIGURE 2B
Summer Water Temperatures in the Middle Yuba River below Our House Dam (15-minute interval)

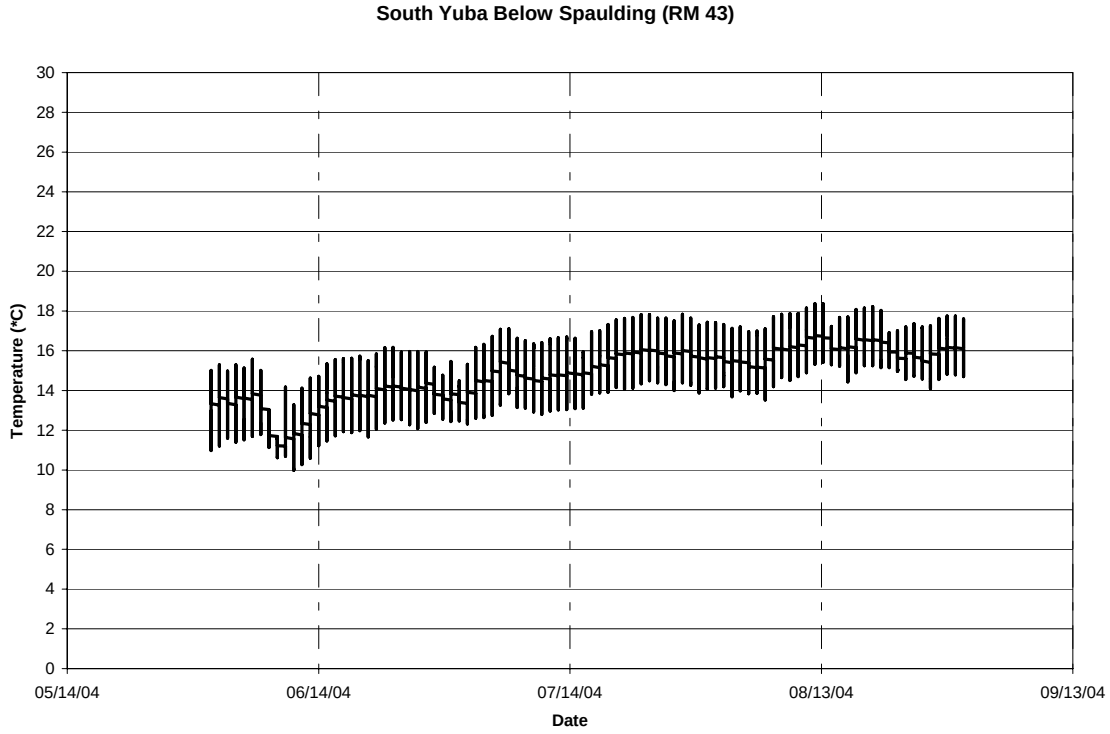


FIGURE 3A
Summer Water Temperatures in the South Yuba River below Lake Spaulding at Langs Crossing (15-minute interval)

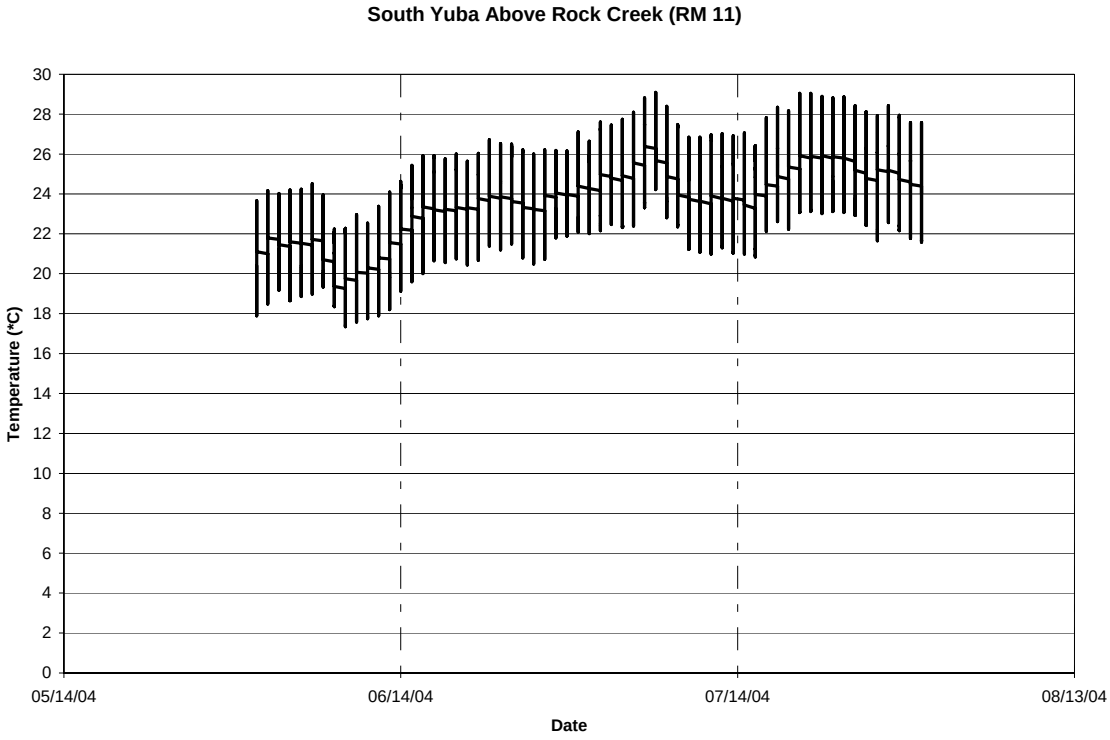


FIGURE 3B
Summer water temperatures in the South Yuba River above Rock Creek (15-minute interval)

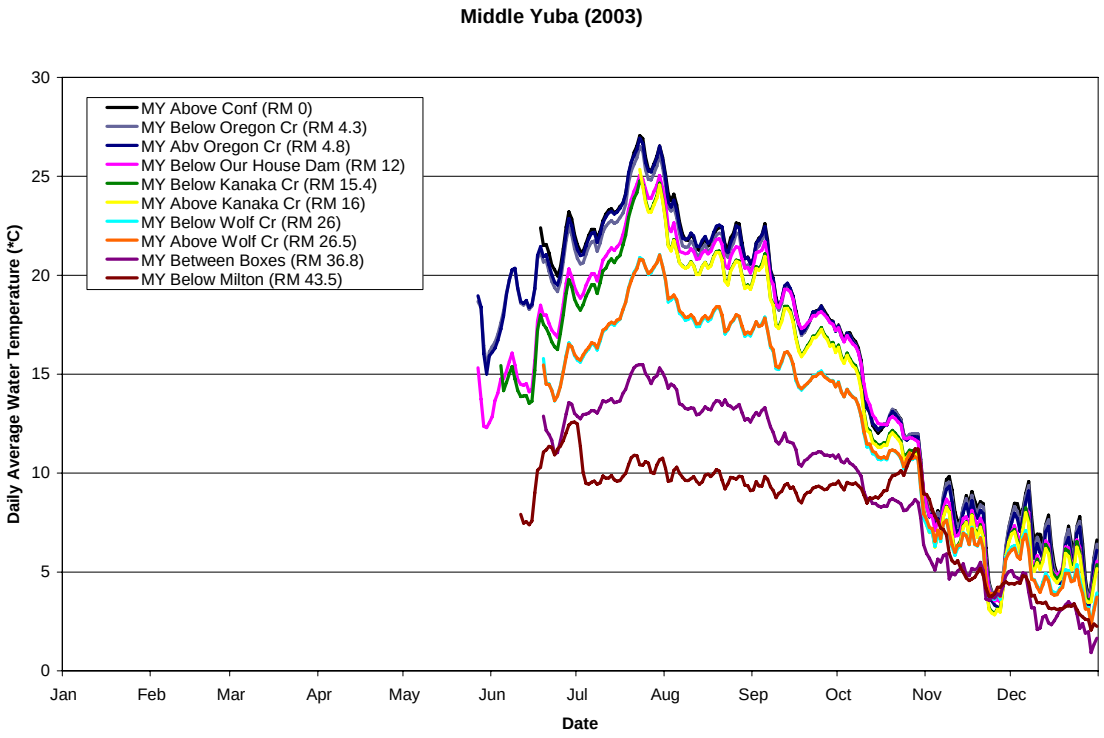


FIGURE 4A
Water Temperatures in the Middle Yuba River (daily average) During 2003

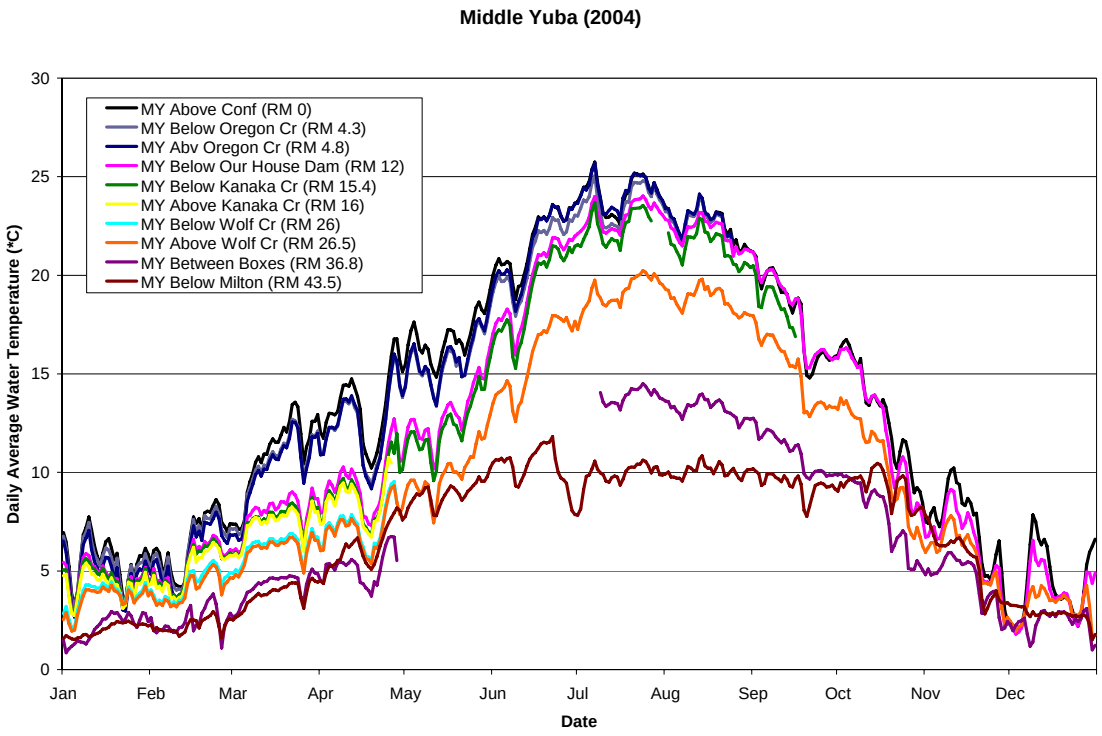


FIGURE 4B
Water Temperatures in the Middle Yuba River (daily average) During 2004

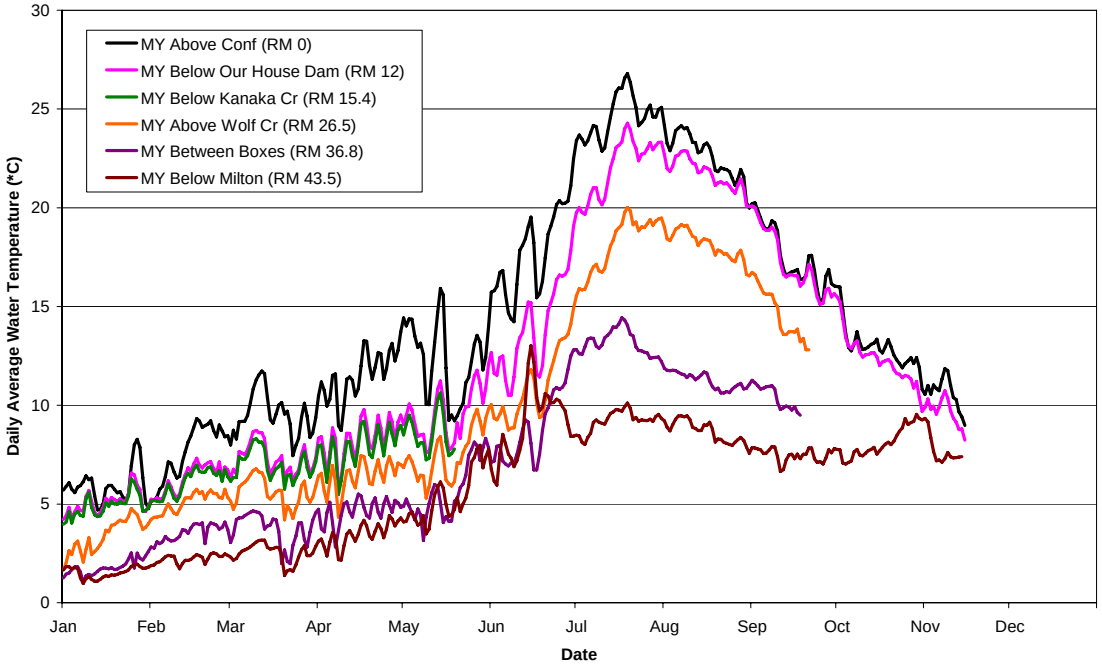


FIGURE 4C
Water Temperatures in the Middle Yuba River (daily average) During 2005

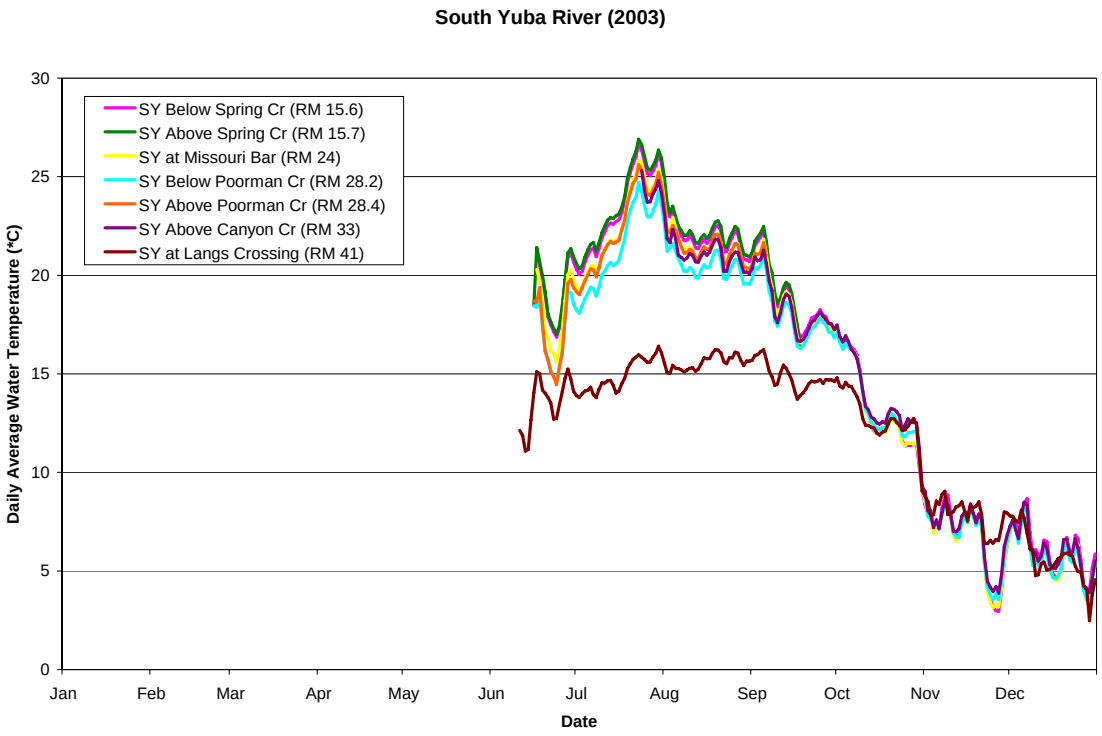


FIGURE 5A
Water Temperatures in the South Yuba River (daily average) During 2003

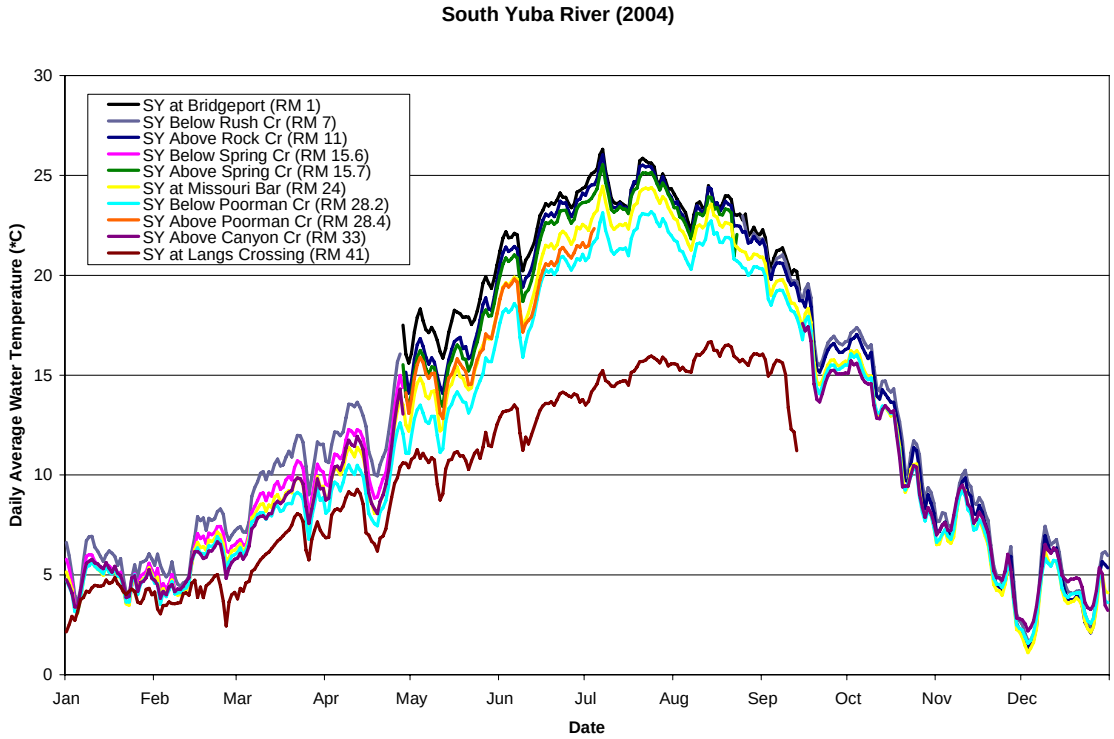


FIGURE 5B
Water Temperatures in the South Yuba River (daily average) During 2004

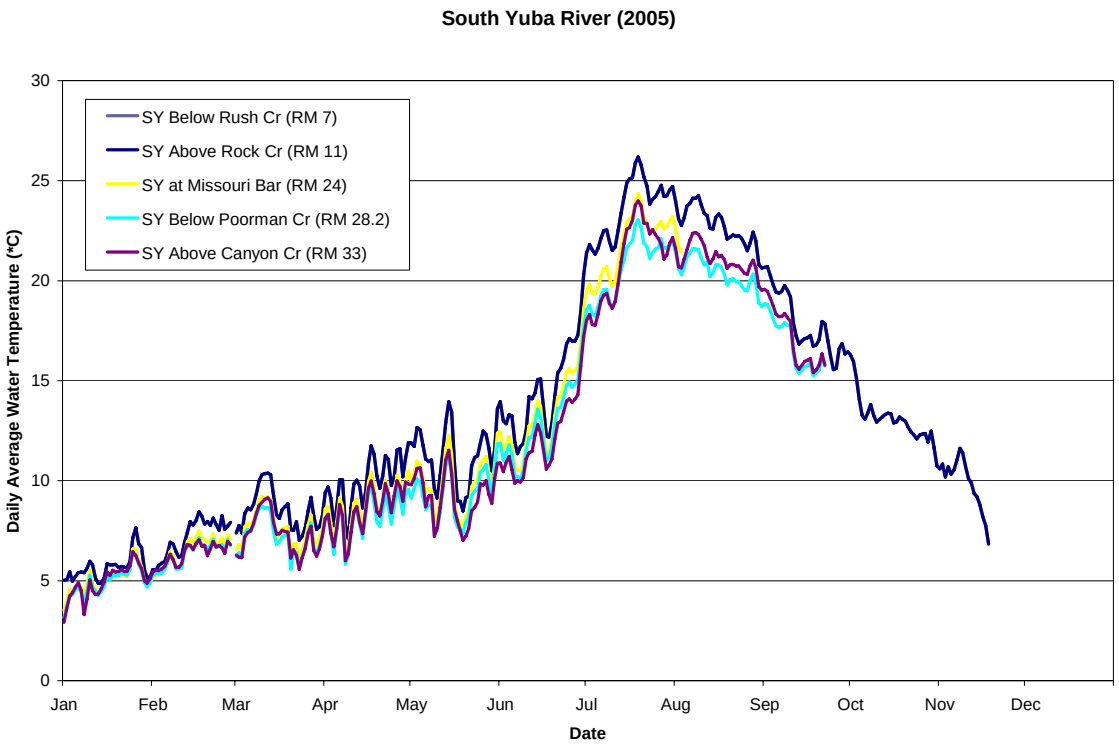


FIGURE 5C
Water Temperatures in the South Yuba River (daily average) During 2005

The data collected during the 2003-2005 sampling period suggest that either meteorological and hydrologic conditions did not vary substantially during this period or that stream temperatures are not substantially affected by these conditions. Maximum daily average temperatures during the year were nearly identical from year to year, although timing of the date with maximum temperature shifted by up to 3 weeks. Even though flows were substantially higher in 2003 in the South Yuba River, maximum daily average temperatures were similar to 2004; also, the maximum water temperature occurred earlier in 2003 when flows were even higher than in 2004. Minimum temperatures observed during the winter were nearly the same in all years.

## Reservoir Profiles

Surface temperatures in the upstream reservoirs peaked in August and generally declined substantially (3°C to 5.5°C [5.5°F to 10°F] by October. Water temperatures declined with increasing depth, sometimes decreasing rapidly over a relatively narrow depth band (thermocline). Where a thermocline existed, it was generally at least 10 m (33 feet) below the surface. In general, reservoir surface elevations decreased from July through October.

The water temperature profiles in Jackson Meadows suggest that this reservoir is strongly stratified during the summer, and that this stratification is maintained at approximately the same depth throughout the summer, even though the surface elevation declines (Figure 6). The observed temperature profile in Bowman Lake indicates little, if any, stratification or development of a cold-water pool (Figure 7). The water temperature profiles observed in Lake Spaulding suggest that the reservoir is strongly stratified during the summer, with a cold-water pool developing at least 30 m (100 feet) below the surface, near the elevation of the outlet (Figure 8). Fordyce Lake exhibits stratification from July through September, with

the elevation of the thermocline declining as the surface elevation declines over the summer. There was no evidence of stratification in October (Figure 9).

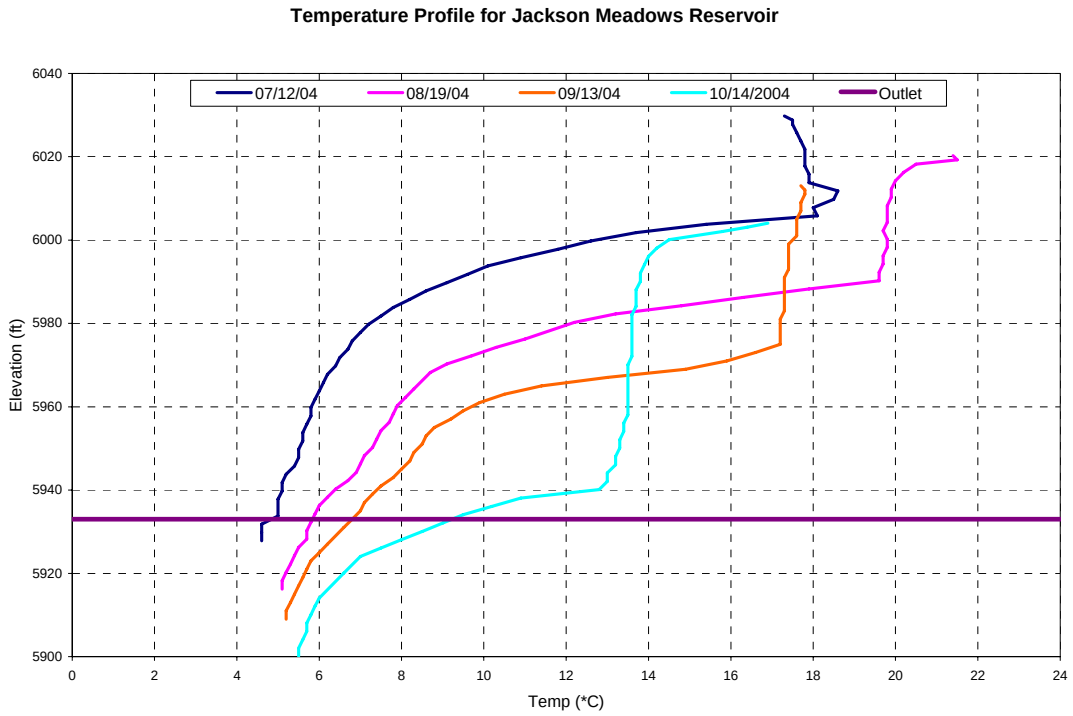


FIGURE 6
Water Temperature Profiles in Jackson Meadows Reservoir During 2004

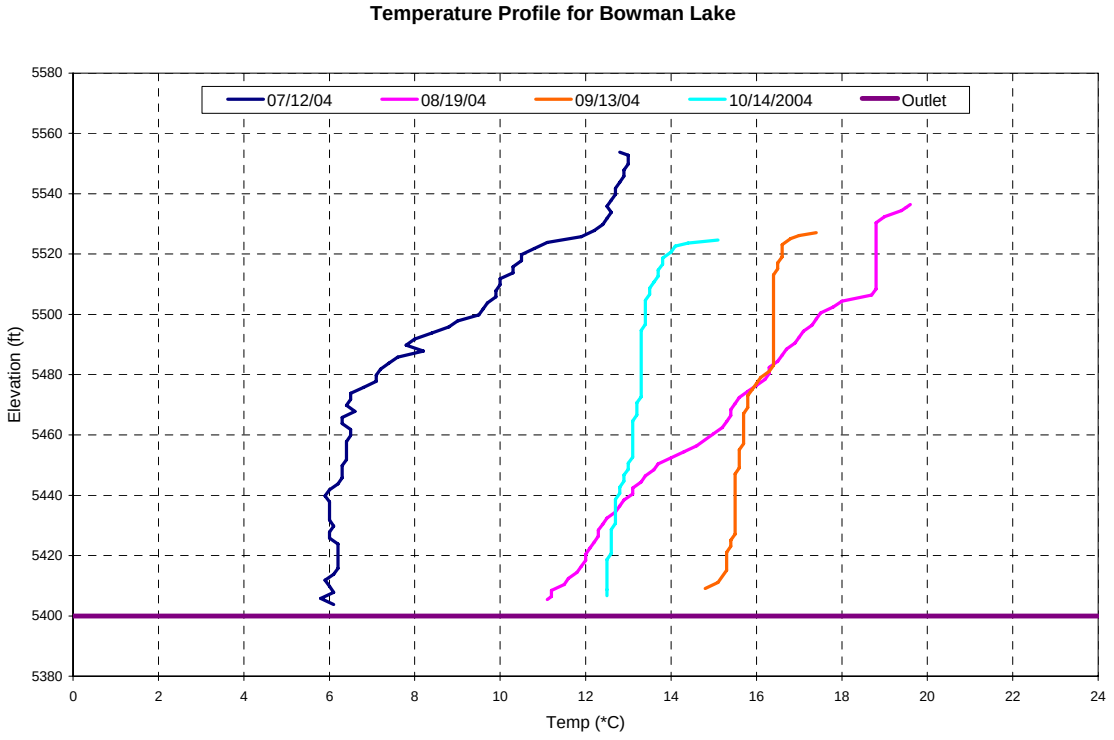


FIGURE 7
Water Temperature Profiles in Bowman Lake During 2004

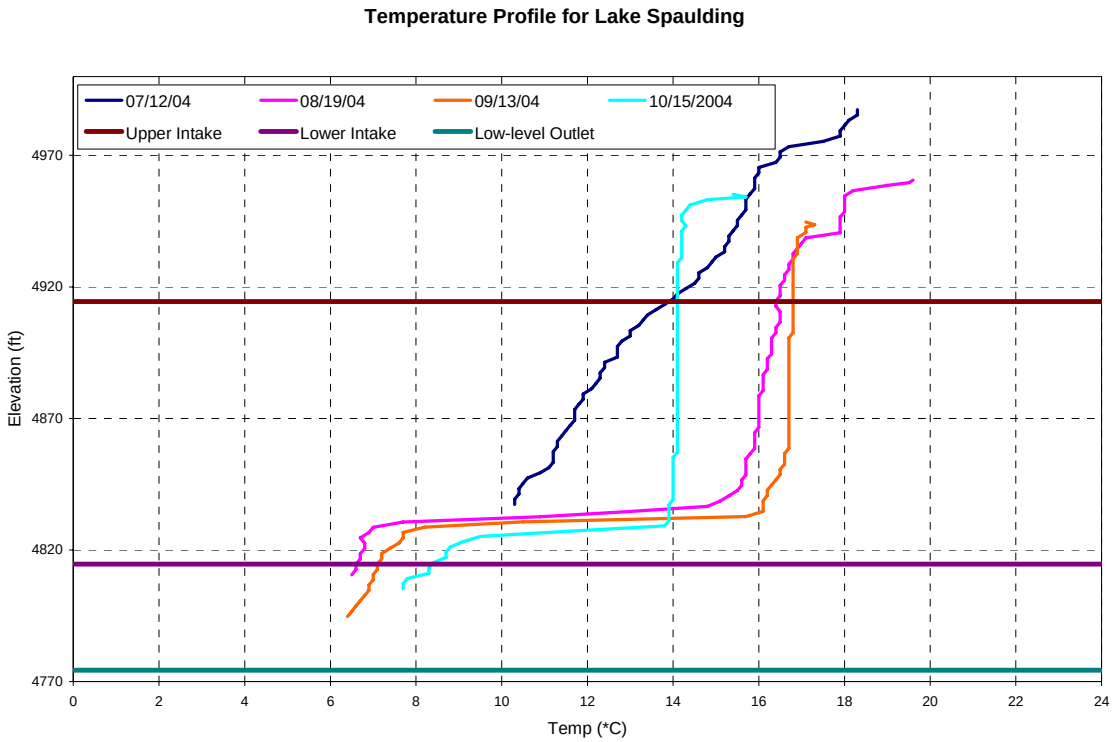


FIGURE 8
Water Temperature Profiles in Lake Spaulding During 2004

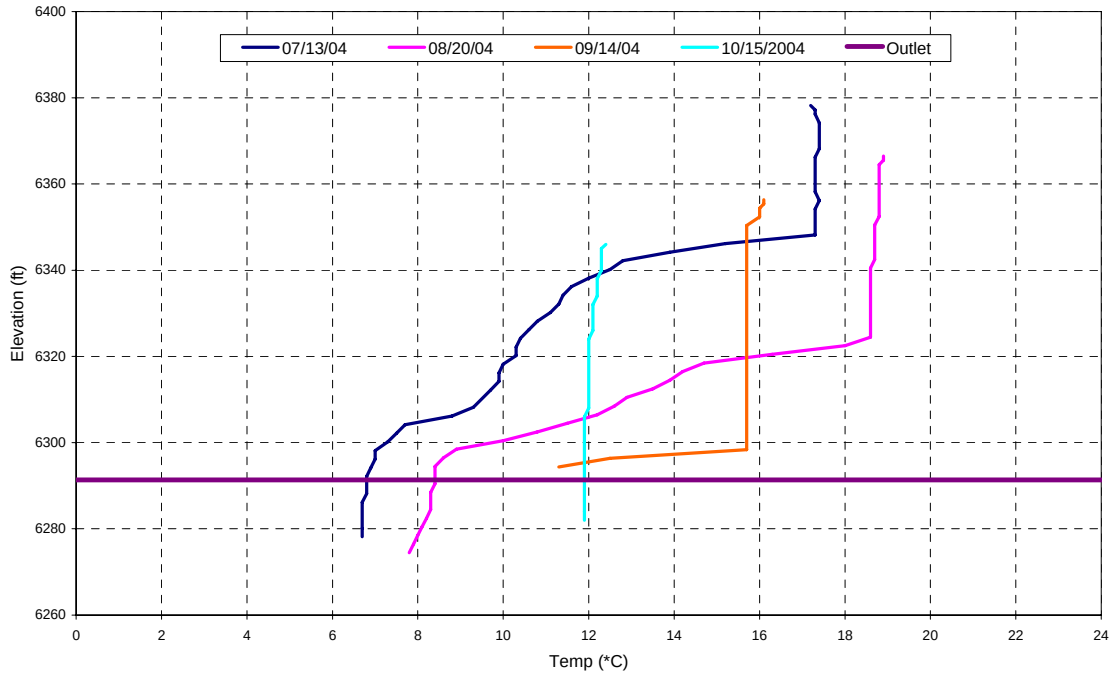


FIGURE 9
Water Temperature Profiles in Fordyce Lake During 2004

## Canal and Inflow Water Temperatures

To compare water temperatures at various points in the canal system and inflows to Lake Spaulding, raw monitoring data were summarized to daily averages. Figures 10 through 15 present the daily average water temperatures in the canal system and upstream of Lake Spaulding in 2004 and 2005. In general, water temperatures do not warm substantially in the canal system as water moves from Milton Reservoir to Bowman Lake with daily average water temperatures remaining near 10°C (50°F). Water warms as it moves through Bowman Lake, leaving the lake at a higher temperature than the water entering from the Milton-Bowman Canal. Water temperatures in the Bowman-Spaulding Canal remain similar from below Bowman Lake to Lake Spaulding, with little evidence of warming. Fordyce Creek has daily average stream temperatures that are slightly higher than those observed in the canal system during the summer. Above Lake Spaulding, summer stream temperatures in the South Yuba River are approximately 5°C (9°F) warmer than below Lake Spaulding at Langs Crossing.

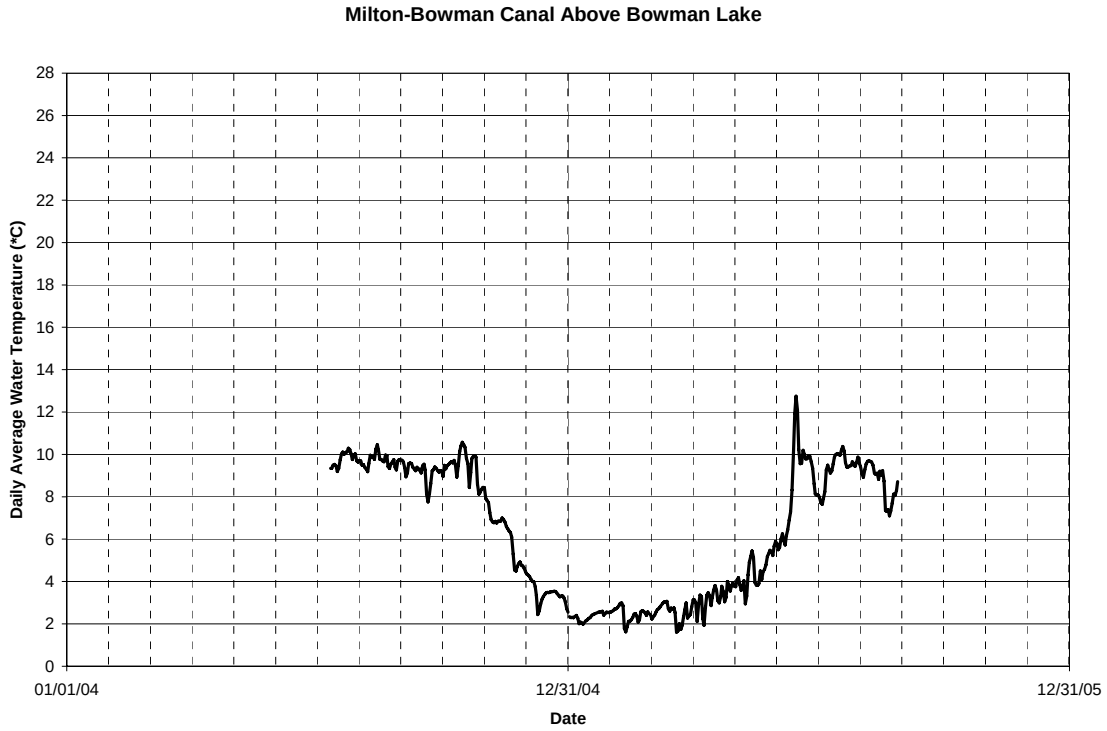


FIGURE 10
Daily Average Water Temperatures in the Milton-Bowman Canal Above Bowman Lake
*Short-duration temperature spikes likely due to operational changes (dewatering)*

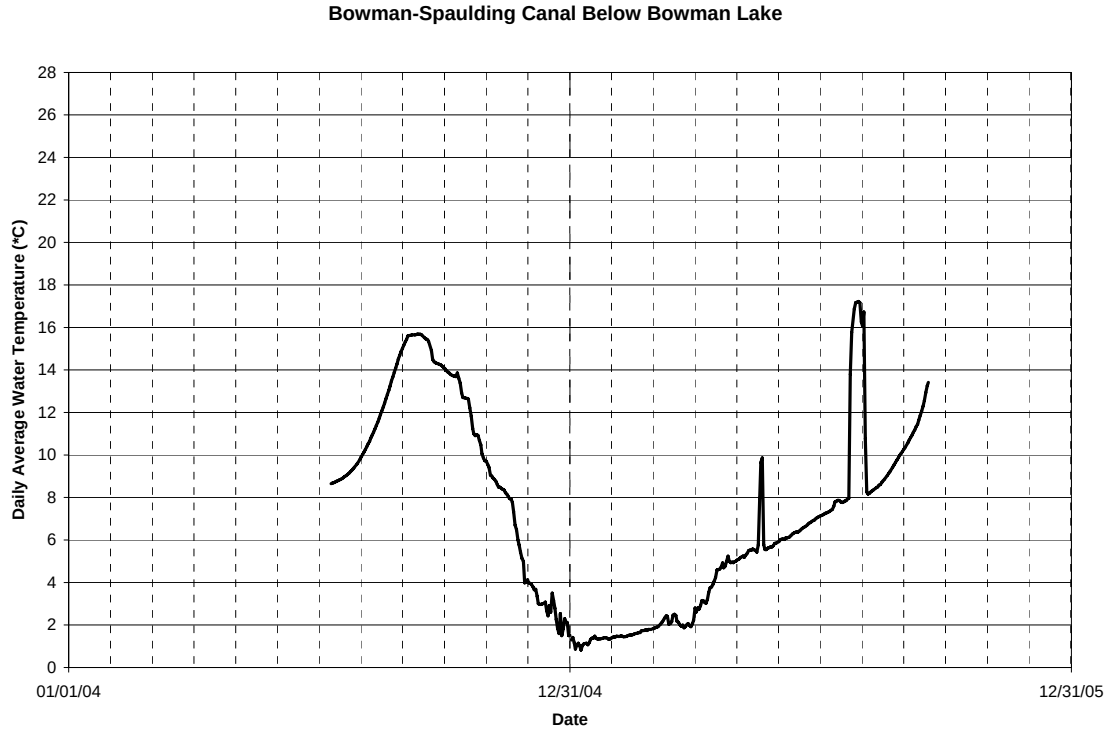


FIGURE 11
Daily Average Water Temperatures in the Bowman-Spaulding Canal Below Bowman Lake
*Short-duration temperature spikes likely due to operational changes (dewatering)*

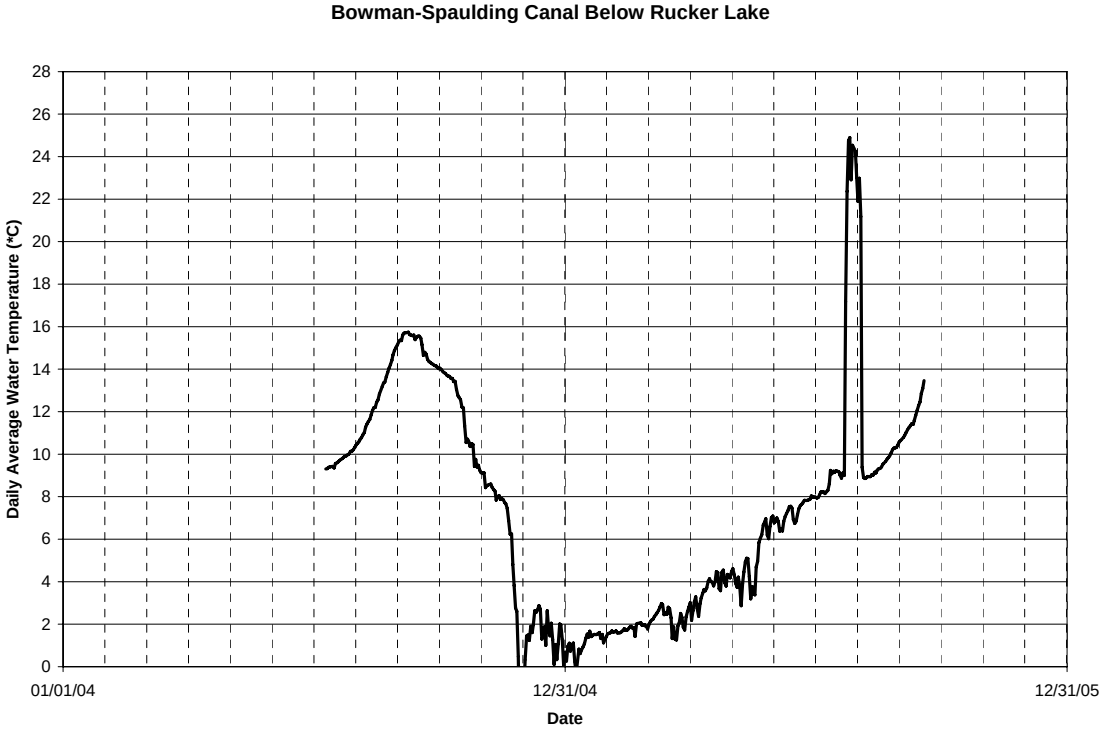


FIGURE 12
Daily Average Water Temperatures in the Bowman-Spaulding Canal Below Rucker Lake
*Short-duration temperature spikes likely due to operational changes (dewatering)*

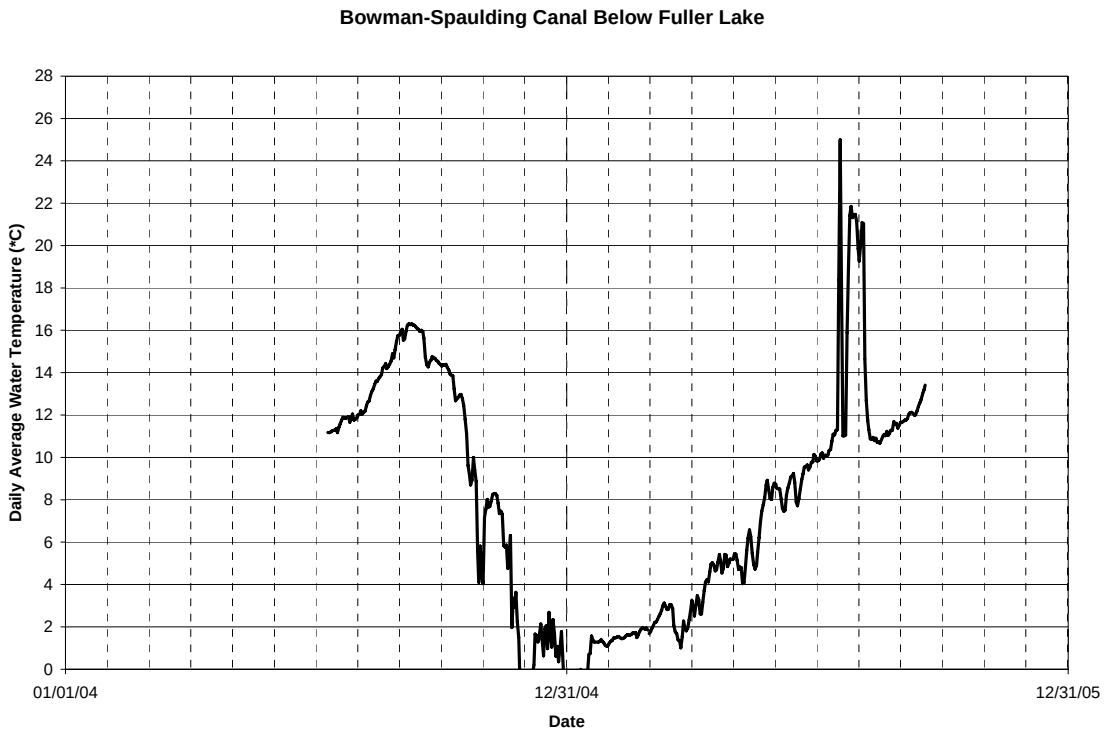


FIGURE 13
Daily Average Water Temperatures in the Bowman-Spaulding Canal Below Fuller Lake
*Short-duration temperature spikes likely due to operational changes (dewatering)*

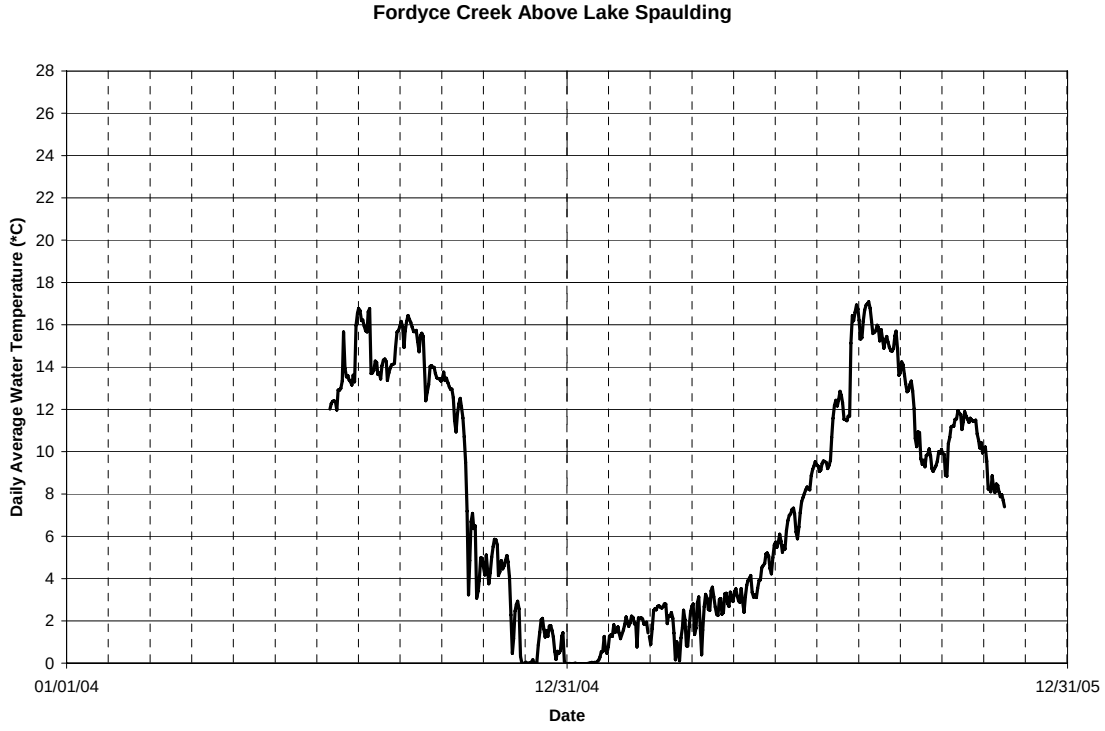


FIGURE 14
Daily Average Water Temperatures in Fordyce Creek Above Lake Spaulding

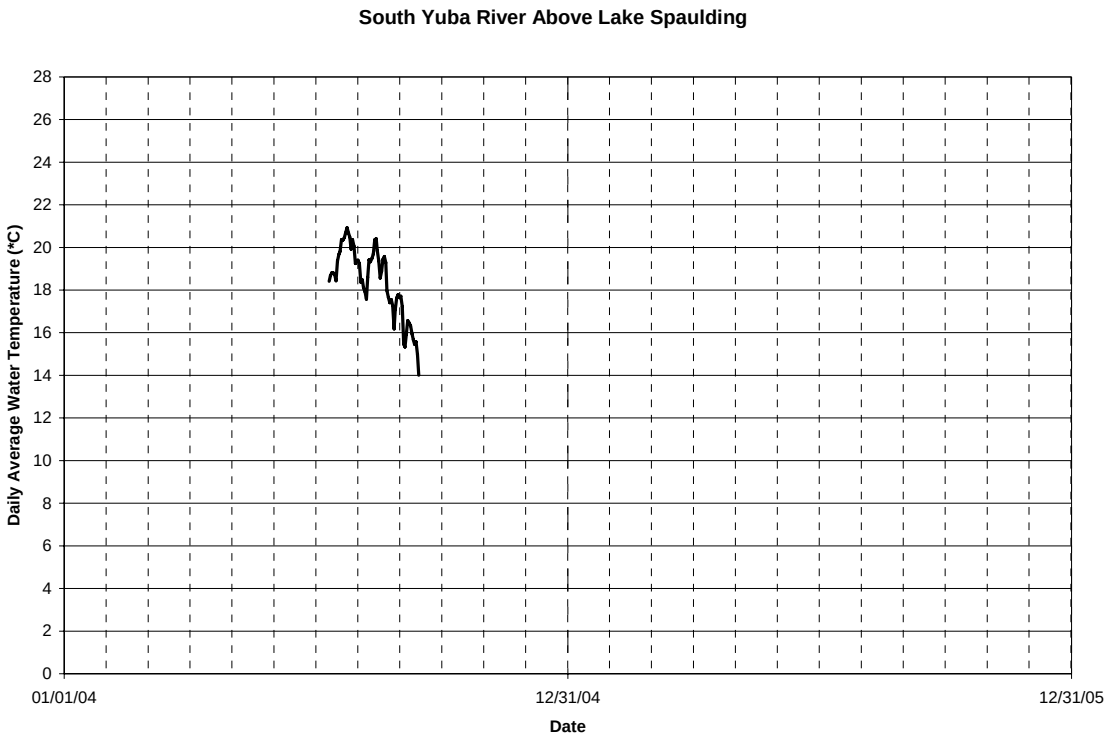


FIGURE 15
Daily Average Water Temperatures in South Yuba River Above Lake Spaulding
*Logger was not recovered in 2005 due to vandalism or loss due to high water*